Time and Information

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Abstract

The relationship between 'information' and 'time' is explored in order to find a solution to the 'Problem of Time'. 'Time' is a 'result' of the conversion of energy into 'information'. The numbers or labels assigned we give to the 'times' when events occur can be '*computed*' from the processing of state information 'flowing' from a Feynman Clock (FC) [1], [2], [3], via a 'Signal', to a Feynman Detector (FD). The ordered set of the 'time' numbers labeling these 'events' can be used to construct the 'direction' and 'dimension' associated with the usual conception of a 'time' axis or coordinate in quantum, classical and relativistic mechanics.

1 Introduction

> **What, then, is time? If no one asks me, I know what it is. If I wish to explain what it is to him who asks me, I do not know**-*St. Augustine [4]*

Can we discover what 'time' is by looking at it as 'information' created by the flow of energy between objects in the universe? If so how is the 'time' produced from this 'information'? What do we mean by 'information' in the context of the quantum systems that compose our world? 'Information' has many meanings from the *description* of the quantum state of an atom in an atomic clock to complex abstract *ideas* about the entire atomic clock 'system' in the 'imagination' of the brain.

> **Information is Physical**-*Rolf Landauer[5]*

Information is treated as a **physical** aspect of our world. It is more than just labels, words, or 'bits' since the *physical state* of a system contains the 'information' which will be processed or computed into the 'times' we use to label the order of events in causal networks and sequences. The quantum world alone is not 'timeless' but has irreversible properties when considering excited states. The quantum world can be 'reversed' or more properly 'reset' by interacting with signals and energy from its 'classical' environment. More specifically 'time' is rooted in the states of systems that create signals which in turn transfer information to other systems. We will define primary state information to be a physical observable or measurable state of a system that can be coupled, paired or 'entangled' with another signal such as a clock generated pulse. A 'triplet' state in a 'memory' or detector can be formed consisting of the signal induced state, the clock pulse state, and the time label counter state that tags the clock pulse with a label. The creation of a triplet states involves a process of 'signal mapping' which will be discussed later.

The triplet state can be operated on to extract the 'time' in the form of **secondary state information**. These numbers are the 'times' that the observer (quantum information processing system) pairs with the observed signals from the 'source' events. The real numbers from the ordered set of events can be used to from a 'dimension' or axis of 'time' mapping the events to a standard clock. The 'dimension of time' is just the dimension of the real number 'line' used to map the 'event time'. Further 'processing' of information mapped on 'timelines' represents **tertiary state information.** This tertiary information is exemplified in higher level mappings of the 'times' to the mathematical and other 'abstract' descriptive languages used to establish to 'meaning' of the temporal information in models of cause and effect for the behaviors of complex systems. Since conventional 'time' is a derived measure of information flow through evolving systems, it should come as no surprise that its application in theoretical models can take many forms. 'Imaginary' and 'multi-dimensional' times are 'possible' in that maps of phenomena can be created using them but these 'constructions' probably ascribe a 'temporal' property to some poorly understood 'non-temporal' aspect of the world that is fundamentally 'informational'.

2   Information, Clocks, and Causal Networks

> **Time must never be thought of as pre-existing in any sense; it is a manufactured quantity**-*Hermann Bondi[6]*

Where does this information originate? Perhaps we can see the essence of the 'problem of time' by comparing two identical 'working' electronic watches. One with a battery and one without. What is the difference between these watches? Energy. The 'powered' watch is an example of a state repeating cyclical 'clock' that generates time 'information' by conversion of the energy (supplied by the battery) into 'signals' that can be read or detected by an observing system or person. The battery provides energy and therefore re-configuration information from the watches '*environment*'. The internal configuration of the atoms and molecules of the watch 'ratchet 'or 'gate' the energy flow through the mechanism creating an excited state (tick) which decays to a ground state (tock). This conversion of energy into information is perceived as either the 'movement of hands' or the display of sequential numbers. These signals define the 'time' labels we map to other observed events. The working watch 'manufactures' the signals that we process and interpret as 'time'. The watch without the battery is 'timeless' providing no other forces act upon it to change its structure.

> **It would be quite appealing if atoms interacting with photons (or unstable elementary particles) already carried the arrow of time that expresses the global evolution of nature.-***Ilya Prigogine and Isabelle Stengers [7]*

Let us look at a quantum watch whose energy to information conversion occurs at the quantum scale. These quantum watches can be created as one-time-only instant clocks at the site of multiple particle collisions in a target or they may be quantum watches waiting for 'batteries' in the form of photons for instance as in the case of atoms in their ground states. Once an unstable configuration of matter and energy is created in a local region of space, we can say that a watch or clock now exists there. In the case of quantum instabilities in space, the total process mapping the incoming to the outgoing signals can be modeled from Feynman Diagrams in which 'time' is removed as a 'dimension' since the creation of unstable excited states occurs in space but not 'in time'. A *time-independent* Feynman Diagram is used to map the types, energies and '**trajectories**' of 'incoming' fundamental particles resulting in the creation of a **Feynman Clock** (or **FC**).

Remark 1 *Note that a 'trajectory' in this paper is really a composite 'system' (SEN) composed of a source (FC, CEN), signal (e.g. photon, phonon, etc.), detector (FD mode of a FC, or a CEN) and a* spatial map *of these quantum objects.*

2.1   Three Assumptions

We will make a conceptual leap inspired by the quantum hypothesis which assumed that 'particles' can be here then there without passing through the space in between. In the following theory of 'time' as a form of 'information' we will make *three assumptions.*

The *first assumption* is that *the method of Feynman Diagrams* [9], [10], used to understand particle collisions or 'reactions' at extremely high energies, can be modified into **'time-independent**' *maps* (FCs), that represent the *initial* and *final* **configuration states** of a single 'system'. This system may be formed by incoming particles interacting with a target or '**quantum clock**' [11]. The 'transitions' from the initial excited state to any of many possible 'final' lower energy states is accompanied by the production of outgoing signals. These configuration transformations are 'time-independent' in the sense that the transitions are fundamentally **geometric**. Any conventional *'times'* associated with these *events* are 'labels' that identify the causal and therefore 'temporal' relationships of the states of the changing system in the observer's detectors (e.g. eyes). In other words the total 'geometric' configuration (as identified by the mass and energy distributions of the components of the system in space) are in a sense 'quantized' into configuration states when the system acts as a single entity. This allows us to look at these special configuration transitions, in an evolutionary universe, not as happening *'in time'* but producing 'time' information carried by signals created in the *decay process.* Once the signals (e.g. photons, phonons, images, etc.) are 'detected' they can be labeled or stamped with 'time numbers' by the observing system. This process couples or entangles the induced information states in a detector (or 'memory') with 'coincident' standard clock states. The classical 'event time' can be extracted by disentangling this complex compound state into a classical time 'number'. Ordered sets of these number and event pairs can be used to create 'timelines' or the time 'axis' of *space-time.*

The *second assumption* is that once an unstable state or configuration of matter is created in a quantum system, it must then decay irreversibly. During this process 'signals' are created. The FC decays with the production of outgoing 'signals' and perhaps leaving a remnant (in the center of mass frame) particle or **Feynman Detector** (or **FD**). It is at the point of creation of a FC that the **irreversible quantum arrow of time (QAT)**can be defined with respect to a lower energy reconfiguration state or FD. The quantum arrow of time is not really a 'time' arrow but a one-way function mapping the unstable configuration of a system to a more stable one [12]. The QAT represents 'temporal directionality' at the most fundamental scale. It has been overlooked because of the confusion between 'time reversal' and 'process reversal' in microscopic physics.

This system could still be reconfigured into a FC state by detection of another signal. This **is not** *'time reversal'* but a time-independent *'process reversal'* in which a 'signal' from the classical environment reconfigures a FD into a FC. The 'problem of time' is the 'paradox' of the apparent *reversibility* 'in time' of particle collisions compared to the apparent irreversibility of the macroscopic world built from these quantum systems. This is characterized by the Second Law of Thermodynamics with its associated 'entropy' directed 'arrows of time'. The key to the solution of the 'problem' is that the reversibility of the particle collision process *does not imply* that the unstable state of the transient aggregate quantum system (FC) is 'reversible', since it is the unstable state that must decay irreversibly!

The *third assumption* is that networks of FCs (acting 'internally' with their irreversible QATs and driven by detection or processing of external **reversible Classical Arrow of Time (CAT)** 'reset' or excitation signals) can support **collective excitations states in networks** that **decay irreversibly**. This is the basis for **Collective Excitation Networks (CENs)** and **Collective**

Excitation (CE) signals such as those seen in nuclear multipole vibrations, condensed matter interactions with phonons and 'sound waves', global quantum states in superconductors, and excitons in photosynthetic 'detectors'[13]. Collective excitations are the key to understanding how hierarchical systems emerge from their microscopic components. The QATs of these atomic and molecular components acting collectively as a single system can generate the arrows of time that we associate with chemical, biological and cosmic processes. The key is that the coupling of these nodes in a network now form a new larger scale 'quantum' system.

A 'classical' system emerges when it's basic network components (Signal-'connectors', and the FC or CEN 'nodes' and 'gates') are 'space-like' separated with respect to information flow. In other words if the states of the components can't be coupled or **'entangled'** [14], [15] in order to support a collective state then the information flow may be a causal sequence of 'isolated' states in a step-by-step information transfer process which we will call a **Sequential Excitation Network (SEN)**. Examples of this include, 'conventional' computers, sequential chemical reactions in the cell, nerve impulse transmission, and higher level metabolic processes in animals. FCs and CENs form the building blocks of SENs which can also act like a 'single' system with novel collective 'classical' behaviors.

3 'Sources' of Information

The reconfiguration or 'decay' of an unstable quantum system (a Feynman Clock or FC) into a more 'stable' state (Feynman Detector mode of the FC) plus a 'signal', occurs with a finite 'lifetime'. This 'time number' is created by the 'dimensional' conversion (using Planck's Constant) of the '*energy of reconfiguration*' **information**, $\mathbf{I}_R$ (note that this is **primary state information**), into the 'time' associated with the reconfiguration of the system in an excited state to a lower energy configuration. The **mapping** of the reconfiguration information to a real number is the result of the interaction of the unstable quantum system with its classical 'environment'. The 'map' between the quantum system and its environment is Planck's Constant. This **Planck Mapping Function**, $\hbar$, is the quantitative measure of the coupling of quantum systems to their 'environments'. This function 'resides' in the 'observer' system and relates the primary information at the quantum scale to the derived ('computed') secondary information from it. Note that secondary information is also 'physical' in that it may be the state of a single quantum system or a collective state in a network of these systems.

4 The Quantum Arrow of Time

We start with a simple two-level quantum system (Feynman Clock) with only one excited and one ground state; $|E^*\rangle \equiv |1\rangle$ and $|E_0\rangle \equiv |0\rangle$ respectively. A photon 'signal' with energy, $\Delta E_\nu = E^* - E_0 = h\nu = hc/\lambda$ is heading towards the FC in state $|0\rangle$. The composite 'classical' system $|S_C\rangle$ composed of the 'free' photon $|\lambda\rangle$ and the target FC $|0\rangle$ is:

$$|S_0\rangle = |\lambda\rangle + |E_0\rangle = |1\rangle + |0\rangle \tag{1}$$

Absorption of the photon results in the creation of the excited FC state represented by direct or tensor product of the photon and target states:

$$|S^*\rangle = |\lambda\rangle \otimes |E_0\rangle = |1\rangle \otimes |0\rangle \Longrightarrow |0\rangle \otimes |1\rangle = |\lambda\rangle \otimes |E^*\rangle = |0,1\rangle = |S_{FC}\rangle \tag{2}$$

This is now a FC in an unstable configuration. It will decay irreversibly with a 'lifetime' determined by the degree of instability created by the internal fundamental interactions between the matter and

4

energy distributions of the components of the system. The 'geometry' of the system is driven by these interactions into a more 'symmetric' configuration in which the energy of the total system is minimized. The decay 'lifetime' [12] of this excited state is:

$$\tau_{S_{FC}} \equiv \frac{\hbar}{\Gamma_{FC}} = \frac{\hbar}{|\langle 1, E_0 \mid H_{E^* \to E_0} \mid 0, E^* \rangle|^2} = \frac{\hbar}{\mathbf{I}_R} \tag{3}$$

Note that the denominator, $\mathbf{I}_R$, is usually referred to as the 'decay rate', Γ. The $\left| \langle \Psi_{(E_0)} \mid H_{E^* \to E_0} \mid \Psi_{(E^*)} \rangle \right|^2$ term has units of 'energy'. This is the **reconfiguration information** encoded in the energy transported by the signal that exits the quantum system into the classical environment. An **image state** is created in a spatially distinct Feynman Detector by resonant absorption of the signal. The image state marks the transition of the FD into its FC mode. The source FC, signal, and FD together define a *node-arc-node* segment (a '**trajectory**' for 'information' qubits as defined above). Connected segments can be used to build hierarchical causal networks in which the flow of 'information' defines a primitive form of 'quantum computer'.

The decay of the excited state is irreversible in the sense that once the unstable state is created it must decay. The bottom term in the above equation is the 'intrinsic energy of reconfiguration' for an unstable quantum system. The system in a ground state will not spontaneously become excited without a signal from it's environment. The 'excited' state may be *recreated* by another incoming photon of the same energy, but this requires information to be put into the FC from it's environment. This is not 'time reversal' but a 'reconfiguration' process.

The excited state transition to a ground state allows us to *create* an *irreversible* '**Quantum Arrow of Time**'(**QAT**) *which always 'points' from the unstable state to a more stable one.* The QAT applies to excited states for individual particles and also systems of particles that act *collectively* as a single larger 'quantum' system. Collective Excitations (CEs) of these composite systems are the key to understanding irreversible processes in larger systems composed of many interacting FCs. These Collective Excitation Networks (CENs) of FCs can support new behaviors and states in complex systems such as those seen in giant nuclear multipole vibrations, phonon scattering and absorption of photons in solids, sound waves, and electromagnetic waves in the brain.

The QAT defined by the irreversible decay of unstable states of quantum systems **closes** "*the gap between the dynamical description of quantum mechanics and the evolutionary description associated with entropy*"(Ilya Prigogine, P.47, [8]) and solves the 'quantum paradox' if we see that the decay of an unstable state is a form of 'self-measurement'. The 'decay' or initiation of the reconfiguration process of the internal 'geometry' is triggered by fundamental interactions (forces) acting on the asymmetric distributions of energy and matter. The fundamental instabilities involved with excited states of matter provide the basis for the irreversible QAT and therefore create the possibility of a 'unified' formulation of quantum theory and the fundamental interactions of matter [3] from their origins in the Big Bang to their 'expression' as the complex collective states of consciousness occurring in the brain.

5   The Classical Arrows of Time

The environment of a Feynman Clock can provide information (typically from the signal created by another clock) in the form of energy carrying resonant signals that can reconfigure or reset a system into an unstable state. Once a 'signal' in space has 'decoupled' from its' source at the quantum level, one can think of the signal as mapping information flow from a source to a detector in a classical space (ignoring for the moment 'interference term's arising from interactions of entangled signals with other quantum systems). The classical 'trajectory' of the signal can be thought of as Sequential Excitation

Network of the vacuum between source and the target detector. This 'trajectory' is a **Classical Arrow of Time (CAT).** The key to the classical arrow of time is the 'space' in which quantum systems (FCs and CENs) and their signals operate. 'Classical' properties of systems emerge in two cases. The first is 'large' spatial separations between FCs that allow them to keep their local 'identity'. This can be used in reverse to define the 'largeness of the separations' by gauging the strength of the interactions between two systems if any. The second is the 'large numbers effect' of many bodies acting collectively as a single 'Newtonian' object. This is what we usually mean by 'massive' objects whose behaviors can be described by classical dynamics. Again 'massive' can be defined in reverse by identifying the scale at which collective 'classical' properties of an object decouple into the properties of the individual components.

6   Complex Systems: Diffusion, Entropy, and Hierarchical Arrows of Time

What happens when an ensemble of FCs act as a single n-body system? Lets look first at gases. The thermodynamics of gases is well known for 'equilibrium' ensembles of atoms, molecules and gas-like particles such as stars in galaxies and galaxies in clusters. Is the **diffusion** of a gas a causal network? Yes, but what we shall call an 'open' on weakly 'wired' one where the 'trajectories' of signals are probabilistic [8]. Diffusion represents a special case in which the gas components forming the 'system' act both as 'particles' and 'signals'. Their collective behaviors and motions form a 'random' or 'open' network with a 'collective excitation' interpreted as the 'temperature'. This is in contrast to the hard 'wiring' of transistors and other components in integrated circuit chips whose electron signal trajectories are well defined. Phase transitions correspond to CEs in systems in which a population of FCs from a CEN. Prigogine recognized this collective aspect to phase transitions:

> **"It is at this global level, at the level of populations, that the symmetry between past and future is broken, and science can recognize the flow of time"**
> *Ilya Prigogine* [8]

If we take this one step further we can see that these population 'arrows of time' are the result of the interaction of the FCs in the population acting as a new meso-FC system (CEN) with global CEs whose irreversible decay from an excited state can be used to create the 'CEN Arrows of Time' he is observing in the collective 'resonances' of complex systems from gases to the brain. At this point the global behaviors of an 'open' or 'gas-like' system may be described using probabilistic methods ignoring the 'identity' of the individual FCs leading to a statistical formulation of classical mechanics. One can 'define' an arrow time associated wit this global behavior, but this is the scale at which irreversibility emerges. As we have seen above the QAT associated with FCs and CENs gives us a glimpse of the fundamental source of irreversible behavior at the microscopic level. This method does not apply for 'closed' or 'hard-wired' non-gas-like causal networks of FCs (CENs) supporting collective excitations and behaviors. The methods of quantum computation [5], the method of collective excitations [19], [18], [17], and causal network theory are more appropriate for the description of 'arrows of time' at plateaus of complexity (POCs) in many body systems when one wants to preserve the quantum aspects of the FCs and yet describe the global behaviors of CENs without resorting to '**coarse graining**'.

Entropy production, $P(E)$, (as a function of the '*energy of reconfiguration*') by a Feynman Clock decaying from an excited state to a ground state with an change in energy given by, $\Delta E_\nu = E^* - E_0 = h\nu = hc/\lambda$, provides another way of manufacturing 'time'. We have the production of 'entropy' term **per unit 'time'**, $P(E)$, for a non-isolated system interacting with its environment defined by:

$$P(E) = \frac{dS_{FC}}{dt_{entropy}} \tag{4}$$

Solving for the 'lifetime' of this entropy production process and seeing that this is just the same as the 'decay' lifetime for the 2-state FC above we have:

$$\Delta t_{entropy} = \int_{t(E_0)}^{t(E^*)} dt_{entropy} = \int_{P(E_0)}^{P(E*)} \frac{1}{P(E)} dS_{FC} = \frac{\hbar}{\Delta E_\nu} = \frac{\hbar}{\Gamma_{FC}} = \frac{\hbar}{|\langle 1, E_0 \mid H_{E^* \to E_0} \mid 0, E^* \rangle|^2} = \tau_{FC} \tag{5}$$

This allows us to make a correspondence between the QAT of a 2-state FC model to the 'thermo-dynamic arrow of time' associated with the production of 'entropy' by the decay of an unstable state where:

$$dS_{FC} = dS_{\Delta E_\nu} + dS_\lambda + dS_{VAC} \tag{6}$$

This is the total entropy change in the compound system of the FC interacting with it's 'vacuum environment', via the creation of a 'signal' , λ. The internal entropy change of the FC is $dS_{\Delta E_\nu}$, the entropy transfer across the FC 'boundary' (e.g. nuclear decay with the production of a gamma photon) is dS_λ, and the entropy change in the 'vacuum environment' is dS_{VAC}. Perhaps the most important point here is that the *dimensional conversion of reconfiguration information* using Planck's constant into the 'lifetime', τ_{FC}, of the FC (primary information) **connects** the *'time difference'*, $\Delta t_{entropy}$, (secondary information) of the 'constructed' thermodynamic arrow of time 'map' between two configuration states of the FC. This includes the flow of information from the FC to it's environment by creation of a photon 'signal' projected onto the vacuum energy density of space.

The superposition of the photon on the vacuum creates the 'classical' component of the total system. This classical state of a 'free' photon propagating in space is the basis of the 'classical arrow of time' (CAT) associated with the source-to-sink 'electromagnetic arrow of time' in classical and relativistic electrodynamics. We see here that construction of macroscopic **hierarchical arrows of time** used to map configuration transitions in complex systems are built from the flow of physical information origi-nating in the irreversible QAT of FCs (and CENs) in conjunction with the 'reversible' CATs associated with the 'free' signals in space that create unstable FC and CEN systems via the fundamental particle interactions at the microscopic scale.

7   The Conversion of Information into 'Time'

At this point we will use the techniques of quantum computation to show how signals generated by the irreversible decay of an excited state of a FC can transfer information via signals to FDs in causal networks. The creation of the time label numbers we read off clocks requires an observing system to process quantum sate information into the maps of the 'cause' and 'effect' for our sensory data from our environments. Time is a label or number associated with 'processed' signal information held in a detector or memory.

8   'Computing' Time and the Creation of 'Moments'

In summary we can see that the basic way to compute 'time' from the flow of information between systems in the universe can be built on a simple two state model. This model is really a 'time-independent' quantum computer in which fundamental irreversible quantum processes coupled to reversible information flow in the systems classical environment can be used to build complex hierarchical systems through the phenomena of collective excitations occurring at '**Plateaus of Complexity' (POCs).** These POCs may be cellular membranes or boundary surfaces encapsulating causal networks and quantum computers processing chemical and higher level information.

9   Acknowledgments

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